

Preliminary and Regional Reports

The Use of Irrigation for Frost Protection for Blueberry in the Southeastern United States

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SUMMARY. Freeze events between January and April can result in major crop and economic losses for growers of low-chill, early-ripening varieties of blueberry (*Vaccinium* sp.) in Florida and Georgia. The objective of this research was to determine current responses by blueberry growers to freeze events. Blueberry growers in Florida and Georgia were surveyed about frost protection decision criteria. Growers had differing opinions on when to make the decision to frost-protect blueberry crops. Almost all (98.9%) of the respondents (n = 94) who reported using at least one method of active frost protection reported using irrigation. Farm size, as measured by blueberry acreage, did not influence decisions regarding the use of active frost protection measures. Blueberry growers, on average, reported that a loss of up to 30% to 39% of their crop could be tolerated and still produce a marketable crop. However, they may have been overly cautious at the early bud stages, with ≈40% and 55% of respondents protecting at the bud swell and tight cluster stages, respectively. Understanding the use of irrigation as a frost protection practice in the southeastern United States can aid in improving frost protection recommendations, helping growers maximize yield and saving water and money.

Blueberry acreage in Florida and Georgia has more than doubled since 2000. In 2016, blueberries were harvested from

4700 acres in Florida and 16,900 acres in Georgia. The two states accounted for 23.3% of the total U.S. blueberry harvested area (U.S. Department of Agriculture, 2017). Despite early-ripening varieties being susceptible to spring frost injury

(Strik and Yarborough, 2005), low-chill, early harvest southern highbush blueberries [SHB (*Vaccinium corymbosum* interspecific hybrids)] have been extensively planted in this region to take advantage of pricing for entrance into early U.S. market windows (Brazelton, 2015; England, 2015). SHB varieties begin to flower in January in both Florida and Georgia, with frost events occurring from January until April. Depending on the floral bud development stage and when temperatures drop to freezing or below, damage can be significant (Warmund et al., 2008). As a result, frost-protection measures commonly are used to mitigate crop loss in Florida and Georgia (England, 2015; NeSmith, 2008).

Cost of orchard establishment can be \$10,000 to \$12,000 per acre or more (Fonsah et al., 2013; Singerman et al., 2016). Most growers use low-volume (usually drip) irrigation systems to address crop water requirements and overhead irrigation for frost protection. Frost protection, primarily overhead irrigation systems, can add another \$2300 per acre to establishment costs (Singerman et al., 2016). Once established, operating costs for frost protection through overhead irrigation can be low (as compared with wind machines and heaters) (Poling, 2008). With relatively low operating costs, the main barrier for the use of frost protection is its limited effectiveness. In general, when temperature drops to -7°C or wind speed increases to $16\text{ km}\cdot\text{h}^{-1}$ or above, frost protection may not be effective. Other matters that growers should consider in frost-protecting their crops include increased evaporative cooling due to wind, the potential for poor ice formation, ice accumulation breaking and stripping flowers from the plant, and water restrictions due to regulatory requirements or

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Units

To convert U.S. to SI, multiply by	U.S. unit	SI unit	To convert SI to U.S., multiply by
0.4047	acre(s)	ha	2.4711
0.3048	ft	m	3.2808
0.0929	ft ²	m ²	10.7639
3.7854	gal	L	0.2642
25.4	inch(es)	mm	0.0394
3.6000	kWh	MJ	0.2778
1.6093	mph	km·h ⁻¹	0.6214
6.8948	psi	kPa	0.1450
(°F - 32) ÷ 1.8	°F	°C	(°C × 1.8) + 32

physical limitations of the irrigation system (Perry, 1998; Poling, 2008; Snyder and Melo-Abreu, 2005).

Given these constraints, growers initiate frost protection in advance of a frost or freeze event when the temperature is anticipated to reach critical levels where lethal damage to reproductive tissue can occur (critical bud temperature values). Figure 1 illustrates the established critical temperatures for different blueberry bud stages (Patten et al., 1991; Spiers, 1978). Another problematic constraint is the information gaps related to variety, climate, and bud stage in recommendations provided to growers in Florida and Georgia. As a result, growers in Florida and Georgia must rely on critical bud temperature information developed for other regions.

Overall, the decision to start frost protection at a particular time depends on the cost, information available, and risk attitude of growers to adjust their practices in response to frost forecasts (Crane et al., 2010; Hu et al., 2006; Klockow et al., 2010; Kusunose and Mahmood, 2016; Mase and Prokopy, 2014; Stewart et al., 1984). The study by Stewart

et al. (1984), which focused on frost-protection decisions of fruit growers in central Washington, found multiple on-farm weather resources and strategies available to growers to mitigate frost. Perceptions of the weather forecast quality and applicability of the forecast to growers' production systems were crucial for the decision to frost-protect fruit crops.

Research shows that more studies examining the determinants of frost-protection decisions are needed, given the potentially high economic impact of frost and the need for more efficient frost-protection systems and opportunities to save water and energy by developing precision frost-protection technologies (Chevalier et al., 2012; Simnitt et al., 2017). The objective of this project was to identify, by survey, the prevalence of frost-protection systems, the use of information resources to mitigate damage caused by frost events, and the decision timing for operating a frost-protection system by Florida and Georgia blueberry growers.

Materials and methods

A paper-based survey was developed that contained 19 questions

directed to identify freeze-protection practices and decision criteria. The target population for the survey was commercial blueberry growers of Florida and Georgia. Questions focused on decision management based on bud stage, meteorological information, and informational resources. Further, questions were asked to identify varieties under frost protection, equipment used to frost-protect crops, and areas of frost protection. Before distribution to growers, the survey instrument was pretested, and input from the pretests was incorporated into the final survey language and design. The Florida and Georgia blueberry surveys were submitted to the University of Florida and University of Georgia Institutional Review Boards, respectively, where they received exempt status.

The Florida blueberry survey was distributed and collected at the Fall Blueberry Short Course of the Florida Blueberry Grower's Association in Oct. 2015. In Georgia, surveys were administered and collected in collaboration with extension activities at county meetings in southern Georgia between Nov. 2015 and Jan. 2016.

Survey responses were coded and analyzed using SAS (version 9.4; SAS Institute, Cary, NC). Summary statistics, including mean and standard deviation, were calculated for each question, and questions were cross-tabulated and tested for significance using the Pearson's χ^2 test and the Kolmogorov-Smirnov test.

Results and discussion

DEMOGRAPHIC OVERVIEW. After we eliminated nonqualifying respondents, the final number in the survey was 106. Of the 106 respondents, 94 used active frost protection, with 46 from Florida (48.9%) and 48 from Georgia (51.1%). Most respondents were from farms of less than 51 acres (Table 1). Taking the midpoint for each of the acreage response intervals, we estimate that these Florida and Georgia growers manage about 1696 and 2850 acres, respectively, or about 37.7% and 19% of the total blueberry acreage in their respective states.

Most growers had experience with blueberry production, with the average number of years growing



Fig. 1. Blueberry floral bud stages: Stage 1 = dormant—no visible swelling, bud scales completely enclose florets; Stage 2 = bud swell—visible swelling of bud, scales separating, flowers still completely enclosed (critical temperature range from 10 to 15 °F); Stage 3 = tight cluster—bud scales separated, apices of flowers visible (critical temperature range from 20 to 23 °F); Stage 4 = early pink—bud scales abscised, individual flowers, typically pinkish in color, distinguishable (critical temperature range from 23 to 25 °F); Stage 5 = late pink—individual flowers separated, corollas unexpanded and closed (critical temperature range from 24 to 27 °F); Stage 6 = full bloom—corollas open (critical temperature of 28 °F); and Stage 7 = petal fall—corollas dropped (critical temperature of 32 °F) (Michigan State University, 2012; Spiers, 1978). Photos by Elizabeth Conlan; (°F – 32) ÷ 1.8 = °C.

blueberries being 10.1 years in Florida and 13.1 in Georgia. A significantly larger (Wilcoxon rank-sum test, $P = 0.05$) proportion of Florida respondents ($\approx 40\%$) had grown blueberries for 6 years or less, compared with less than 10% of Georgia respondents, reflecting the relative youth of Florida's blueberry industry.

In both states, growers reported producing a mix of varieties, mostly SHB. The median number of varieties selected by respondents from the questionnaire list was three; in addition, many respondents, including those growers with rabbiteye blueberry (*Vaccinium ashei*) varieties, selected the "other" option (Table 2). The SHB varieties

Farthing and Emerald were popular in both states; in addition, the majority of respondents in Florida reported growing Jewel, whereas the majority in Georgia reported growing Star.

Of the respondents who reported using at least one method of active frost protection, almost all (98.9%) used irrigation for frost protection (Table 3). The emphasis was on using a frost-protection system that minimizes production losses with the least amount of damage to the plants. The water source for irrigation was statistically different between Florida and Georgia, with Florida growers using more groundwater and Georgia growers using more on-farm

ponds. (Table 4). Factors contributing to the predominance of well water as a source for freeze protection in Florida are the ease of access (with shallow aquifers available in most blueberry-producing Florida regions) and the water-permitting procedures (with permits usually making allowances for freeze protection that are not counted against the water permitted for supplemental irrigation). In Georgia, most growers who freeze-protect blueberry crops draw water from artificial ponds to reduce well water drawdown.

Sprinkler type also varied by state: wobbler sprinklers in Florida vs. impact sprinklers in Georgia (Table 4). The main difference in the choice of sprinkler type may be that Georgia tends to have longer, more-frequent freezes. Impact sprinklers have changeable nozzles to deliver greater volumes of water, which may be needed in more severe freezes, or to turn the pressure up at the pump to deliver more water without damaging the sprinklers.

INFORMATION CONSIDERED IN FROST-PROTECTION DECISIONS. Growers were asked to evaluate the importance of climatic and crop factors on the decision to initiate irrigation for frost protection (Table 5). Five factors (air temperature, dew point, wind speed, bud stage, and freeze duration) identified in the literature (Perry, 1998; Poling, 2008; Stewart et al., 1984) as important were presented to the growers. Results show that growers placed air temperature, dew point, wind speed, and bud stage as very important indicators, at 77.9%, 74.2%, 77.3%, and 85.1%, respectively, to activate frost protection. By stage 5 (late pink stage) (Fig. 1), less than 10% of the respondents would not frost protect and the majority would begin using the system when the temperature reached 31 °F. Although an irrigation system, once started, should be run until the temperature rises above freezing and the ice is melting or risk crop damage (Snyder and Melo-Abreu, 2005), only 56.8% of the respondents thought the duration of a freeze event was very important.

Location was the only farm characteristic that significantly affected the ranking of importance of the factors related to irrigation initiation.

Table 1. Farm acreage of blueberries reported by growers from Florida and Georgia in response to the question "how many acres on your farm are dedicated to blueberry production?"^z

State	Respondents (no.)	Proportion of responses (%)					
		Less than 5 acres ^y	5–10 acres	11–25 acres	26–50 acres	51–75 acres	More than 75 acres
Florida	44	9.1	18.2	22.7	25.0	9.1	15.9
Georgia	48	6.3	8.3	25.0	16.7	14.6	29.2

^zFrom a survey of freeze protection practices and decision criteria by blueberry growers in Florida and Georgia administered at extension meetings in 2015 and 2016.

^y1 acre = 0.4047 ha.

Table 2. Proportion of blueberry growers in Florida and Georgia who indicated growing specific southern highbush blueberry varieties in response to the survey question "which of the following varieties do you grow commercially? (Mark all that apply)" (n = 93).

Variety	Proportion of respondents (%)		
	Florida	Georgia	Total sample
Farthing	56	71	63
Emerald	93*	65*	78
Jewel	71*	2*	35
Meadowlark	53	38	45
Rebel	7*	50*	29
San Joaquin	2	8	5
Star	16*	92*	55
Other	73*	29*	51

*The difference in proportion of growers producing the variety between states is significantly different at $P \leq 0.01$ using Pearson's χ^2 test.

Table 3. For the blueberry growers in Florida and Georgia who use active frost-protection methods, the relative use of various methods.^z

State	Respondents (no.)	Proportion of respondents (%)			
		Irrigation	Wind machines	Cover	Heat
Florida	46	97.8	2.2	4.4	0.0
Georgia	48	100.0	10.4	0.0	0.0
Total sample	94	98.9	6.4	2.1	0.0

^zThe responses are from a survey of freeze-protection practices and decision criteria by blueberry growers in Florida and Georgia administered at extension meetings in 2015 and 2016 and in response to the question "what frost protection strategies for blueberries do you use? (Mark all that apply)." Since some growers use multiple frost-protection measures, the sum of proportions for various irrigation methods exceed 100%. No statistical differences were found between states using Pearson's χ^2 at $P = 0.1$.

Specifically, wind speed was rated less important by Florida growers [62.8% of Florida respondents rated it as “very important,” compared with 91.1% of respondents in Georgia (χ^2 test, $P = 0.01$)] since windy, advective freeze events could be a greater challenge for growers in Georgia. The analysis of the other farm characteristics (years in blueberry production and size of operation) did not reveal any statistically significant relations (Pearson’s χ^2 test, $P = 0.05$).

Respondents revealed that they regularly access weather information, with 81% gathering information from on-farm meteorological devices. In addition, growers access university-supported systems frequently (Table 6).

In Florida and Georgia, the Florida Automated Weather Network (FAWN) and Georgia Automated Environmental Monitoring Network (GAEMN), respectively, were used occasionally or regularly by $\approx 90\%$ of respondents. FAWN and GAEMN were created to provide weather data from areas throughout Florida and Georgia underserved by the National Weather Service (Chevalier et al., 2012). This suggests growers are interested in comparing their meteorological monitoring devices with an off-farm source, which may add confidence to their decision process. This conclusion is similar to results found by Crane et al. (2010) that most farmers in Georgia used three sources of weather

information to cross-check data from various sources. It should be noted that the survey only asked growers how often they received weather information from these sources and not what sources they use when determining the risk of a future freeze event.

Crane et al. (2010) reported that social networks are important for interpreting the weather information, which includes other growers, extension agents, and business interactions with suppliers and buyers. Our findings are consistent with these results, with the top-ranked resource consulted when deciding to turn on irrigation for frost protection being other growers (62%) (Table 7), who may be considered one of the most

Table 4. Irrigation water source and sprinkler type as reported by blueberry growers in Florida and Georgia in response to the questions “what is the primary source of water for irrigation on your farm?”^z and “what type of sprinkler do you use for blueberry frost protection? (Mark all that apply).”

State	Respondents (no.)	Water source				Respondents (no.)	Sprinkler type		
		Proportion of respondents (%)					Proportion of respondents (%)		
		Ground water	Surface water	On-farm pond	Other		Overhead	Wobbler	Other
Florida	43	88.4	4.7	4.7	2.3	45	40.0*	75.6*	11.1
Georgia	44	34.1	4.6	52.3	9.1	47	89.4*	4.3*	6.4
Total sample	87	60.9	4.6	28.7	5.8	92	65.2	39.1	8.7

^zThe hypothesis that the water source use is the same in the two states was rejected at $P = 0.001$ using Pearson’s χ^2 test.

*Significantly different between rows and $P \leq 0.001$ using Pearson’s χ^2 test.

Table 5. Importance of five factors in the decision to activate an irrigation system for frost protection according to Florida and Georgia blueberry growers responding to the question, “how important are the following factors in deciding whether to turn on your irrigation system?”^z

Factor	Responses (no.)	Proportion of responses (%)				
		Not important	Of little importance	Moderately important	Important	Very important
Air temperature	86	0	0	0	22.1	77.9
Dew point	89	1.1	3.4	4.5	16.9	74.2
Wind speed	88	0	1.1	2.3	19.3	77.3
Bud stage	87	0	0	1.2	13.8	85.1
Expected duration of freeze/frost event	81	3.7	6.2	9.9	23.5	56.8

^zFrom a survey of frost-protection practices and decision criteria administered at extension meetings in 2015 and 2016.

Table 6. For the Florida and Georgia blueberry growers who use active frost protection: Frequency of weather information obtained by survey from four weather sources [the Florida Automated Weather Network (FAWN) was listed on Florida surveys and Georgia Automated Environmental Monitoring Network (GAEMN) was listed on Georgia surveys].^z

Weather sources	Respondents (no.)	Proportion of respondents (%)			
		Never	Rarely	Occasionally	Regularly
On-farm weather system/thermometers	79	5.1	3.8	10.1	81.0
FAWN/GAEMN	84	7.1	2.4	19.1	71.4
NOAA	74	21.7	6.8	28.4	43.2
The Weather Channel (The Weather Co., Atlanta, GA)	82	20.7	2.4	26.8	50.0
Other	48	10.4	8.3	25.0	56.3

^zFrequency data are from a survey of blueberry growers in Florida and Georgia in response to the question “how often do you get your weather information from the following sources?”

NOAA = National Oceanic and Atmospheric Administration.

trusted sources of information by growers (Mase and Prokopy, 2014). This finding supports the “train the trainer” approach to extension programs (Warner et al., 2014), where extension agents rely on communicating with the opinion leaders who then communicate with the rest of the farming community, is reasonable.

State extension services also were consulted about irrigation initiation by

Table 7. Percentage of Florida and Georgia blueberry growers who use information from other growers, extension services, and industry publications when deciding to activate an irrigation system for frost protection (n = 86).^z

Information source	Consulting (%)
Advice from other growers	67.4
Extension, including:	39.5 ^y
Agents	22.1
Extension websites	23.3
Industry publications	27.9

^zResponse data are from a survey of frost-protection practices and decision criteria by blueberry growers in Florida and Georgia to the question, “what resources do you consult when deciding to turn on your irrigation system for freeze protection? (Mark all that apply).”

^yCombined responses related to agents, websites, and other extension products.

more than 20% of growers. Although the use of extension service in general was similar in the two states, extension website resources specifically were significantly more popular in Georgia than in Florida [34% and 10.2% of respondents, respectively (χ^2 test, $P = 0.01$)]. It is routine for Georgia extension agents to distribute University of Georgia extension publications to clients. In contrast, 51.3% of respondents in Florida, compared with 26.1% in Georgia, relied on other resources.

SWITCHING FROST PROTECTION IRRIGATION ON AND OFF. The growers acquire weather information from similar sources (e.g., on-farm weather stations and FAWN or GAEMN), and they also have similar responses toward the importance of following temperature, dew point, and bud stage as criteria for frost protection decision management. However, the survey identifies that growers have differing opinions on when they make the decision to frost protect.

In total, when asked to select only one, 28% of respondents reported using dry bulb air temperature compared with 72% using wet bulb temperature to determine when to use frost protection, with significantly more growers in Florida using the dry bulb

temperature in irrigation initiation [38.5%, compared with 18.6% in Georgia (χ^2 test, $P = 0.05$)].

Examining only the subset of respondents who indicated using wet bulb temperature in determining when to frost-protect crops, we found that the decision when to turn the system on and off varied (Fig. 2). The decision to turn the system on and off was grower-dependent regardless of input information and was influenced by region. The difference among growers is especially noticeable for tight cluster and early pink floral stages, when some growers turn their systems on when temperatures reach 34 to 36 °F, whereas others do not protect. For these two bud stages, responses of Florida and Georgia growers differed greatly. For the tight cluster stage, the majority of Georgia respondents selected “do not protect” (66.7%), whereas only 22.7% of respondents from Florida selected the same answer (χ^2 test, $P = 0.05$). Similarly, for the early pink stage, 25% of the Georgia responses were “do not protect” compared with 4.8% of such responses in Florida. The willingness of some growers to protect at any stage could be due to an information deficit, where growers are unfamiliar with critical bud temperatures. However, given that 85.1% of respondents ranked bud stage as “very important” in the decision to activate irrigation, it could alternatively reflect grower preference for caution in protecting their investment, especially in Florida with higher early season prices.

There is also a range of temperatures used by growers to turn the system off (Fig. 3), which affects the duration of frost-protection irrigation. The decision of when to turn the frost protection on/off can significantly affect water use and potential cost savings to the growers.

Moreover, when asked how many times they had turned on irrigation due to cold temperatures in the past season, the number of events for which growers reported initiating frost protection differed among respondents. From Fall 2014 through Spring 2015, growers activated irrigation an average of 5.2 times (the median was 4), with a range from 0 to 20 times during the season. Georgia respondents reported engaging irrigation systems 5.4 times on average (the median was five), whereas for the

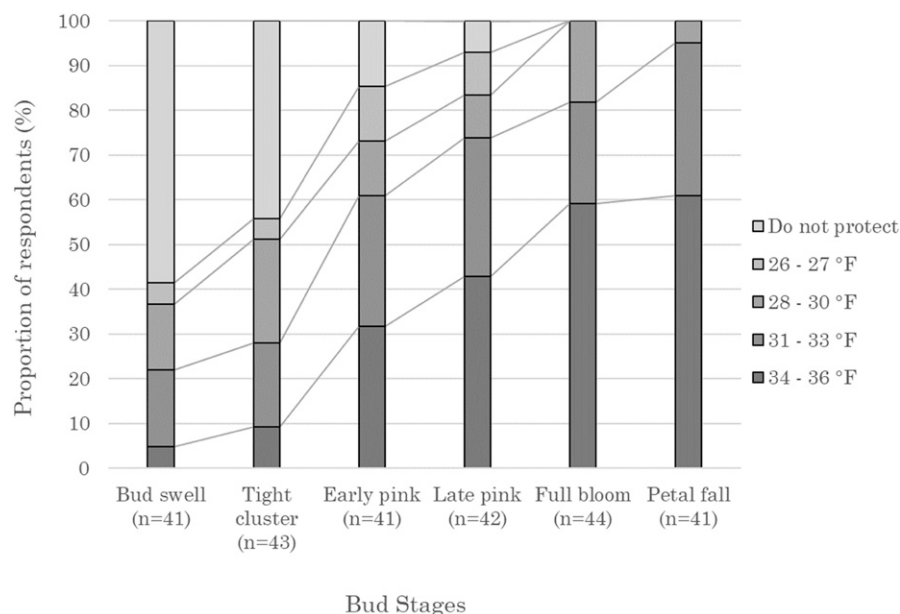


Fig. 2. Proportion of surveyed Florida and Georgia blueberry growers who reported initiating irrigation for frost protection at size different floral bud stages, by temperature range. Responses to the question, “For the following bud stages, for nights where the temperature is predicted to drop below freezing (32 °F), please select the air temperature (°F) at which you turn on your irrigation system for frost protection” (only respondents indicated using wet bulb temperature to determine when to use frost protection); (°F – 32) ÷ 1.8 = °C.

Florida respondents the average was 5.0 times (the median was three) (Fig. 4). State-based differences in the number of events for which growers initiated irrigation for frost protection were statistically inconclusive. Although analysis of variance and median scores tests failed to reject the hypothesis that the responses from Georgia and Florida were drawn from a distribution with the same

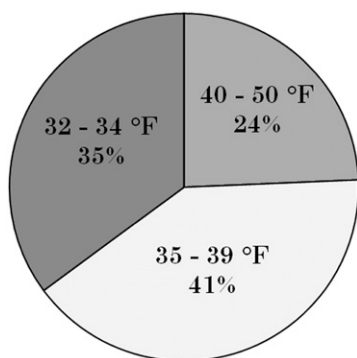


Fig. 3. Proportion of Florida and Georgia blueberry growers who reported turning off their irrigation systems at different temperature ranges after using irrigation as an active frost-protection measure. Responses to the question, “What air temperature (°F) do you consider to be critical for turning off your irrigation system?” [only includes respondents who reported using wet bulb temperature to determine when to use frost protection ($n = 37$)] ($^{\circ}\text{F} - 32 \div 1.8 = ^{\circ}\text{C}$).

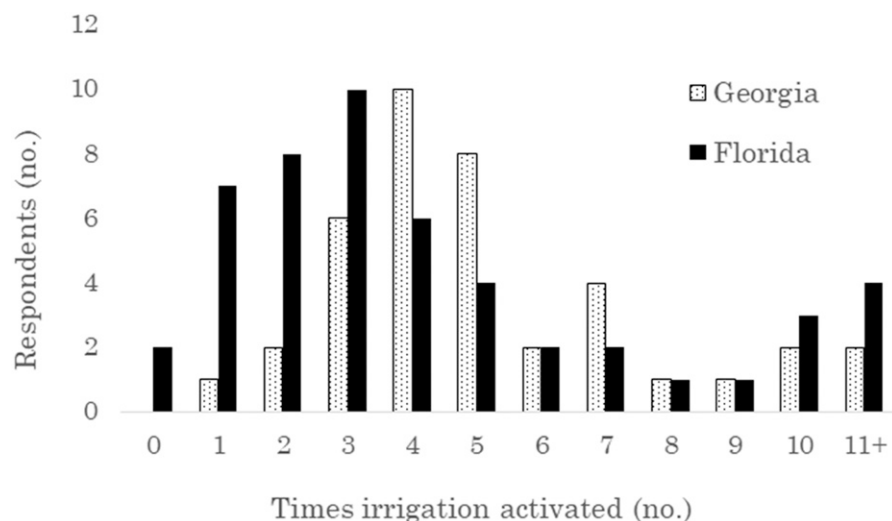


Fig. 4. The number of times blueberry growers in Georgia and Florida reported activating irrigation for frost protection during the Fall 2014 to Spring 2015 season ($n = 89$). Response data are from a survey of frost-protection practices and decision criteria by blueberry growers in Florida and Georgia administered at extension meetings in 2015 and 2016.

mean and median ($P = 0.1$), the two-sided Wilcoxon rank-sum test ($P = 0.1$) and the asymptotic Kolmogorov-Smirnov two-sample test ($P = 0.5$) rejected the hypothesis that the responses were from the same distribution. We further identified five smaller general regions with similar climatological conditions in the two states based on information from AgroClimate (2018) and even within these smaller regions, the range of the responses regarding the number of frost-protection irrigation events was large (Table 8).

The differences in the frost-protection practices may be attributed to growers' perceptions concerning frost-protection risks and the impact of risk on yields (Fig. 5). Approximately 25% of respondents said that they could lose 20% to 29% of floral buds and $\approx 40\%$ said they could lose 30% to 49% of buds and still have sufficient yield to produce a marketable crop.

WATER USE AND COST OF OPERATION FOR IRRIGATED FROST PROTECTION. Of the respondents who use irrigation for frost protection, approximately 69% operate diesel pumping systems, 18% operate electric pump systems, and 13% operate both diesel and electric pumping systems on their farms (Table 9). Many variable inputs are involved in identifying the cost of operation for an irrigated frost-protection system. Inputs include sprinkler rating

(inches per hour), number of sprinklers, pump efficiency rating, gallons of diesel consumed to deliver an acre-inch of water, and the price of a gallon of water. Pump efficiency and gallons consumed per acre-inch of water information can be found in Martin et al. (2011), and sprinkler rating can be calculated from information in Tyson et al. (2006). As an example, sprinkler nozzles are rated for 0.15 inch/h, and the pump demand is 67.9 gal/min per acre in a 60×60 -ft irrigation pattern. To calculate the water used by a sprinkler head, the following relationship can be used:

$$\begin{aligned} & (67.9 \text{ gal/min A})(60 \text{ min/1 h}) \\ & (\text{A inch}/27, 154 \text{ gal}) = 0.15 \text{ inch/h} \end{aligned}$$

In a 60×60 -ft pattern of sprinklers, there are 12.1 sprinklers in an acre ($3600 \text{ ft}^2 \div 43,260 \text{ ft}^2 = 12.1$). In a system pumping at 45 psi with 0 ft of lift, 0.95 gal of diesel will be consumed per acre-inch of water applied. Pump efficiency is considered at 90% efficiency and 1.11 is used as the multiplier, and fuel cost is \$2.50 per gallon of diesel (price as of June 2017) (U.S. Department of Energy, 2018). Given these assumptions, the irrigation costs are:

$$\begin{aligned} & (0.25 \text{ inch/h})(12.1)(1.11)(0.95 \text{ gal}) \\ & (\$2.50/\text{gal}) = \$7.97 \text{ inch/h} \end{aligned}$$

To identify the operational cost using electricity, convert diesel to electricity by using a conversion factor of 14.12 gal/kWh (1.00 diesel factor \times 14.12 electrical factor = 14.12):

$$\begin{aligned} & (0.25 \text{ inch/h})(12.1)(1.11)(0.95/\text{gal}) \\ & \times (14.12 \text{ gal/kWh})(\$0.10 \text{ kWh}) \\ & = \$4.50 \text{ inch/h} \end{aligned}$$

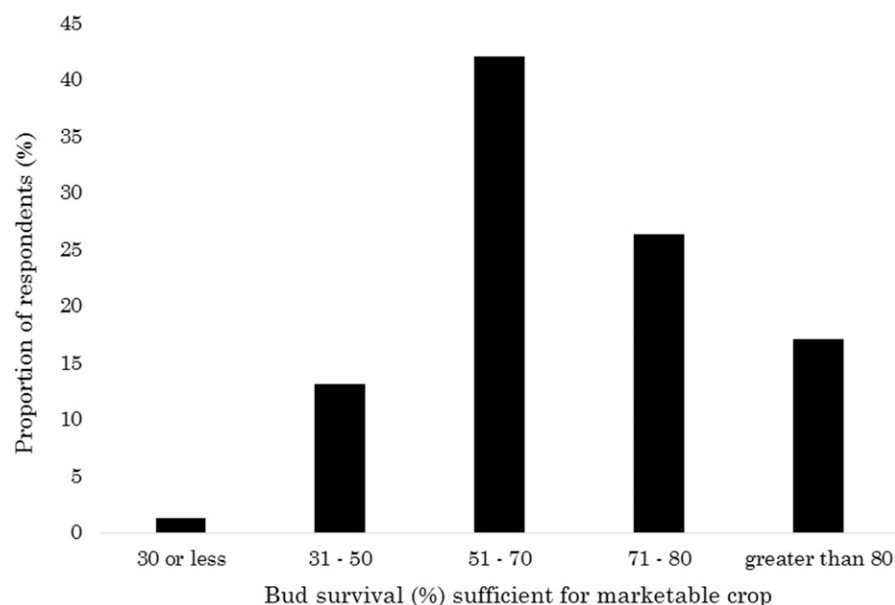
If frost protecting 10 acres for 6 h, the cost of frost protection equals \$478.20 or \$270.00 for diesel or electric systems, respectively. Although growers are divided on the importance of freeze duration and the majority responded that marketable yield could be 51% to 70% bud survival, this suggests growers may delay frost protection to conserve water resources or expenses.

Given that the average number of frost events reported by the growers in both states was about five

Table 8. The self-reported number of times irrigation was activated for frost protection grouped by geographic regions in Florida (FL) and Georgia (GA).^z

Region	Counties	Responses (no.)	Times irrigation activated (no.)			
			Mean	Median	Minimum	Maximum
I	Appling, Atkinson, Bacon (GA); Baker (FL); Brantley, Burke, Coffee, Jeff Davis, Pierce, Wilcox (GA)	33	4.4	4.0	1	10
II	Camden, Charlton, Clinch, Glynn, Lanier (GA); Leon (FL); Ware/Clinch (GA)	16	6.9	6	3	18
III	Alachua, Marion, Putnam, Suwannee (FL)	9	9.0	6	0	20
IV	Citrus, Lake, Sumter (FL)	4	5.5	4.5	3	10
V	Brevard, Hardee, Hillsborough, Pasco, Polk (FL)	20	3.3	2.5	1	12

^zThe responses are from a survey of frost protection practices by blueberry growers in FL and GA. The table combines responses to the questions “what is the county of your operation” and “how many times did you turn your irrigation on due to cold temperatures during the past season (Fall 2014 to Spring 2015)?”

**Fig. 5.** Distribution of responses by Florida and Georgia blueberry growers to the question, “What minimum percentage of bud survival per bush is sufficient to produce a marketable crop?” (n = 81). From a survey of freeze-protection practices and decision criteria by blueberry growers in Florida and Georgia administered at extension meetings in 2015 and 2016.**Table 9.** Types of irrigation pumps used by Florida and Georgia blueberry growers.^z

State	Respondents (no.)	Proportion of respondents (%)		
		Diesel	Electric	Both
Florida	44	79.6	6.8	13.6
Georgia	49	59.2	28.6	12.2
Total sample	93	68.8	18.3	12.9

^zResponse data are from a survey of blueberry grower freeze protection practices and decision criteria answering the question “what type of pump motor is most frequently used?” The proportion of pump motors used between the states was statistically significant (Pearson’s χ^2 test, $P = 0.02$).

(for 2014–15), delaying switching the system on by an hour for each event means a reduction in irrigation by 5 h in the entire season. If sprinkler nozzles are rated for 0.15 inch/h, the pump demand is 67.9 gal/min per acre in a 60 × 60-ft irrigation pattern, or 4074 gal/h per acre, which for an

irrigation run time of 5 h accounts for 20,370 gal/acre. Blueberry acreage varied among respondents, from less than five acres to more than 75 acres. For a grower with five acres of blueberry, a 5-h reduction in irrigation could translate into 101,850 gal of water-use reduction, whereas for

a farmer with 75 acres, this would translate into 1,527,750 gal. For comparison, domestic per-capita water-use rate is 87 gal/d (Marella, 2014), meaning that a family of three people would use 31,777 gal over 1 year. Therefore, even a 5-h reduction in frost-protection irrigation can result in a significant water use savings. Such water-use reduction can be important in the areas like Florida, where traditional water supply sources are not able to sustain increasing water demand driven by the growing population (Economic and Demographic Research, 2018).

Conclusions

To meet consumer demands for blueberry, production in Florida and Georgia increased from 2000 to 2015 × 293% and 274%, respectively. Even though the price per pound decreased for Florida and Georgia by 34% and 15%, respectively (USDA, 2013, 2017), prices remain relatively high, making growers especially concerned about the risk of losing crops due to freeze. Our survey showed that Florida and Georgia growers frost-protect ‘Farthing’ and ‘Emerald’ (Lyrene, 2008; Williamson et al., 2014), which are early flowering varieties in both regions, susceptible to spring frosts. Further, growers are willing to frost-protect crops for the duration of the event and are not overly concerned about the length of time. The majority of growers are willing to wait until the temperature is above the 35 °F wet-bulb temperature before turning the irrigation system off, regardless of operational cost.

A descriptive study of fruit growers in Yakima Valley, WA, found that growers exchanged information when monitoring frost events (Stewart et al.,

1984). Similarly, in our survey, growers were more inclined to consult with other growers for information over other resources. As Stewart et al. (1984) noted, growers tend to communicate with one another during the vigilant period of a freeze despite business competition.

As a result of the risks of freeze-related crop damage and the benefits and drawbacks of irrigation for frost protection, precision is important. The blueberry frost survey provides additional information about frost-protection use, decision criteria related to initiation and termination, sources of information used, and types of irrigation systems. This information can be used by extension to design a strategy to more efficiently disseminate frost warnings and irrigation advice to growers. The survey results also provide a baseline of irrigation frost-protection habits against which to compare future intervention, such as the dissemination of more precise irrigation recommendations.

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